

Studies of the Tsushima Current

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LONG-TERM GOALS

To build an understanding of nature of poleward flowing warm water pathways along eastern boundaries of the ocean.

OBJECTIVES

To understand the structure, interannual and seasonal variability of the Japan Sea's Tsushima Current and its relationship to the upstream condition, the Japan Sea warm core eddy field and subpolar front.

APPROACH

To achieve the objectives, we have adopted a two-pronged approach employing both data analysis and modeling.

A. Data Analysis: Using high quality *in situ* hydrographic data and TOPEX Poseidon altimetric data, define the mean, seasonal and interannual variability of Tsushima Current shear and transport in the context of the geometry of the eastern boundary of the Japan Sea and distribution of warm core eddies.

B. Modeling: Through analytical models, we examine various aspects of the Tsushima Current dynamics as it interacts with boundaries and is subjected to surface cooling.

WORK COMPLETED

A. Data Analysis

Intra-Thermocline Eddies: Using data obtained by the JES program in spring/summer 1999 and winter 2000, by the *Hakuho-maru* in October, 1999, along with archived data including the suite of AXBT profiles, a family of sub-surface eddies within the warm regime of the Japan Sea are identified. The characteristics of these intra-thermocline eddies are described.

Sea Level Slope: During the first phase of our JES research we gathered all available hydrographic and TOPEX POSEIDON (T/P) data within the Sea of Japan, and developed methods to view and merge these data sets into a form that allows us to investigate the sea surface geostrophic currents of the Tsushima Current. We have merged the hydrographic data mean climatic dynamic height (0/200) array with the T/P sea surface height anomaly (SSHA) data thus converting the latter into an approximation of the absolute sea level. An example of ‘corridors’ built around T/P tracks is presented in Figure 1. We have worked with the late 1992 to mid-1997 T/P data set, but we will now with our methods in place, extend the analysis to the more recent T/P data.

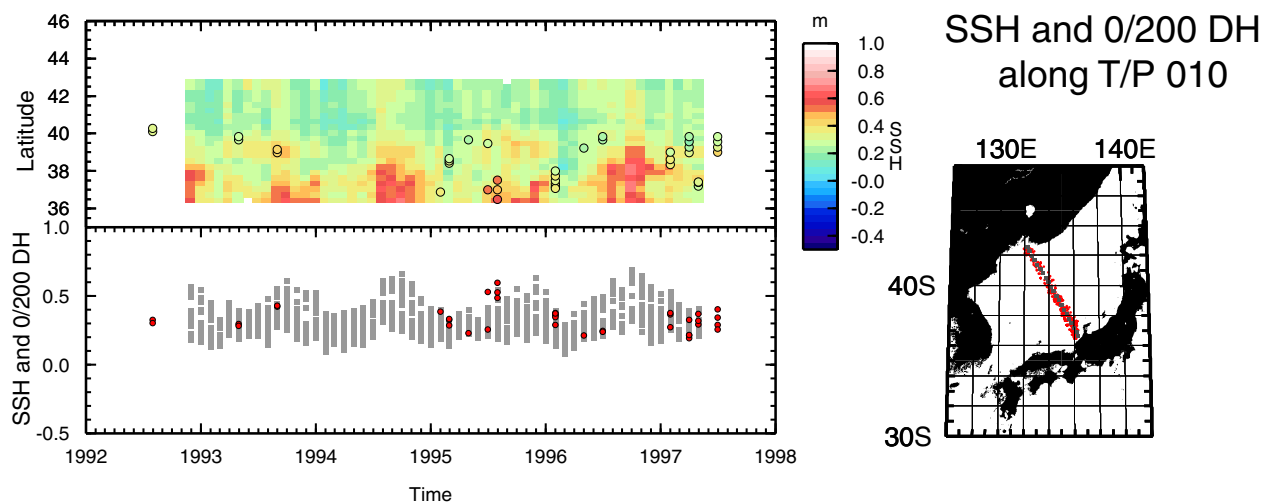


Figure 1. Merged Hydrographic and TOPEX POSEIDON (T/P) Data: T/P data along track 010 (black squares, at 30 km intervals) and 0/200 DH values (red circles). The TOPEX POSEIDON data has been adjusted to a reference dynamic height derived from the archived hydrographic data. For comparison, dynamic height anomaly values from individual hydrographic stations that fall within ± 40 km from T/P location (approximately the deformation Rossby Radius for the region) are shown. Middle panel shows latitude versus time of the sea surface height from the T/P track; the individual stations are shown as circles with same color coding. The lower panel shows sealevel height from the TOPEX POSEIDON data (black squares) and 0/200 DH (red circles) vs. Time.

B. Modeling

Branching of Tsushima Current: We have proposed a robust mechanism for the branching of the Tsushima Current. The research has resulted in a paper in the Journal of Physical Oceanography titled “A model of buoyant throughflow with application to branching of the Tsushima Current”.

Cooling of Tsushima Current: We have constructed a reduced gravity model to examine the effect of surface cooling on the Tsushima Current. The model derivation has led to testable predictions on the current behavior, which are presently compared with the T/P data.

Generation of Tsushima warm eddies: We have proposed a novel mechanism for eddy generation as a buoyant current interacts with a curved boundary. We have completed the analytical derivation, and are

attempting to simulate the process by numerical calculation (in collaboration with Martin Visbeck). The model results are being compared with the T/P data.

Generation of intra-thermocline eddies (ITE): We are developing a three-layer model to examine the process of subduction and its generation of ITE. We have formulated the closure of the model and derived properties of eddies. The model is being evaluated by the AXBT data.

RESULTS

A. Data Analysis

Intra-Thermocline Eddies: [collaborative research with: Craig Lee (UW), Amy Bower and Heather Hunt Furey (WHOI), Claudia F. Giulivi (LDEO) and Lynne Talley (SIO)]: Intra-thermocline eddies (ITE) were observed in the Japan Sea by CTD data (Fig. 2) obtained during various cruises in 1999 and 2000 as well as by archived AXBT data of 1992 to 1995. ITE display a relatively homogeneous core, greater than 100m in thickness, of temperature of less than 12°C with positive oxygen and negative salinity anomalies as compared to surrounding thermocline water. An origin involving winter exposure to the atmosphere, with addition of lower salinity subpolar water is suggested. In contrast to strong surface expressions of the warmer anticyclonic eddies produced as the Tsushima Current curls around the Noto and Oki Island promontories, the ITE have weak sea surface signatures in SST and sea level.

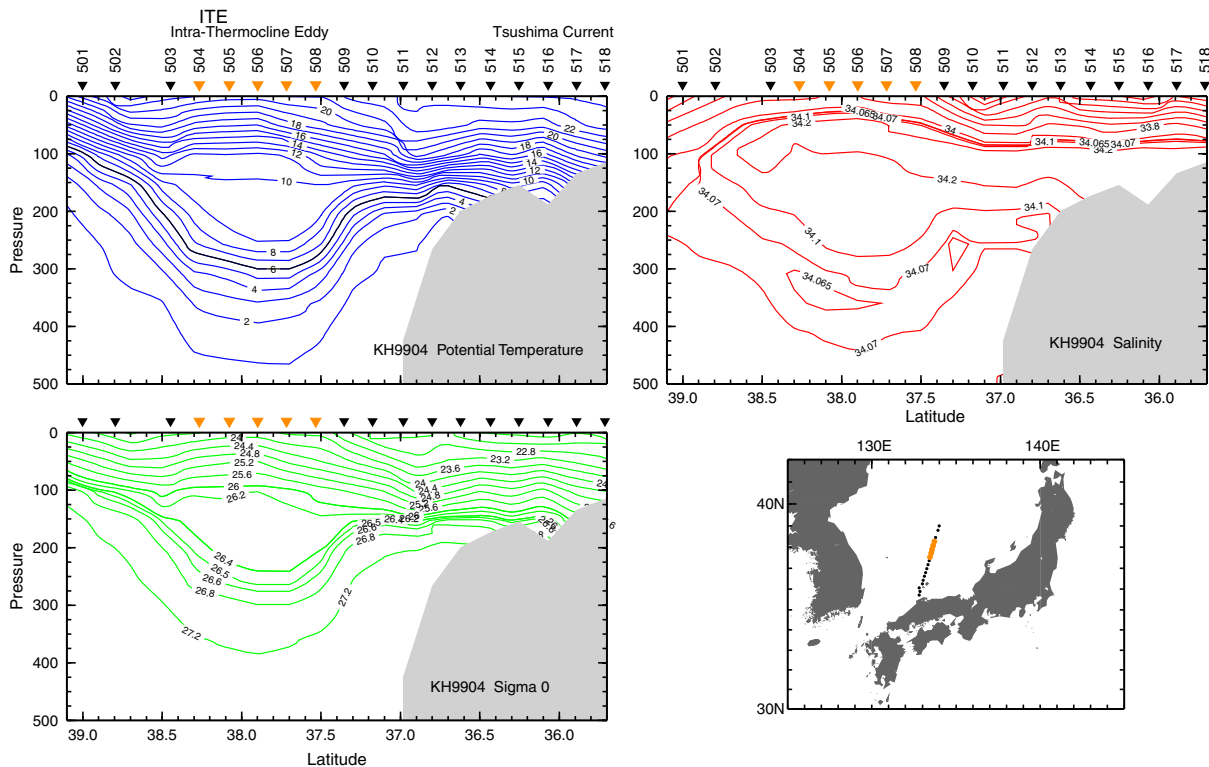


Figure 2. Vertical sections of potential temperature, salinity and potential density across a 10°C intra-thermocline eddy obtained in October 1999 by the Hakuho-Maru of the Ocean Research Institute of the University of Tokyo.

The ITE are capped with a dome of warm upper thermocline water, containing the regional salinity maximum near the 13° to 14°C isotherms. The ITE characteristics are indicative of winter formation within the Japan Sea polar front, possibly at the poleward ends of the three quasi-meanders of the Tsushima Current. The ITE are then subducted below an undisturbed portion of the thermocline to the south. Two groupings of ITE are found: one with core temperatures of near 7°C, the other with core temperatures between 10° to 12°C. The two types are probably produced at different positions across or along the polar front. Winter mixed layers off the coast of Korea closely match the intra-thermocline eddy characteristics, but this may be true of winter waters at other sites along the polar front, such as at the Yamato Rise.

Sea Level Slope: The sea surface slope reveals significant annual and interannual variability. Higher sea level with a stronger Tsushima Current occurs in the latter half of year (Fig. 1). Frequent isolated high sea level is observed north of the main axes of the Tsushima Current, denoting the presence of warm eddies. Strong variability along three quasi-stationary meanders of the Tsushima Current (130°E, 134°E and 137°E) clearly seen in SST images, can also be identified in sea level. Interannual variability occurs in the spatial characteristics of the Tsushima Current.

B. Modeling

Branching of Tsushima Current (Fig. 3a): It is hypothesized that *a buoyant throughflow would branch due to combined effect of hydraulic control and frictional torque exerted by the strait*. With the hydraulic control that maximizes the transport, the buoyant layer would be stretched as it exits the strait. If, in addition, the friction torque exerted by the sill has significantly dissipated the current shear, the above stretching would induce a velocity maximum along the coastal boundary in addition to the frontal jet. When applied to the Tsushima Current, the required condition for branching is amply satisfied, the proposed mechanism thus provides a plausible explanation of the observed feature. Moreover, a favorable comparison between predicted and observed transports supports hydraulic control of the flow.

Cooling of Tsushima Current (Fig. 3b): It is hypothesized that *surface cooling of a buoyant current could enhance its branching feature*. As the cooling reduces the stratification, the layer thickness along the coastal boundary is stretched to accommodate the given transport, thus increasing the cyclonic shear. Since the total flux of mechanical energy is decreased by cooling, the coastal flow thus is strengthened at the expense of the frontal jet. The analytical solution has clearly demonstrated the above effect, and since the current velocity is linked to the surface slope by geostrophy, the T/P data are presently being examined to test the model.

Generation of Tsushima warm eddies (Fig. 3c): It is hypothesized that *eddies could be generated as a buoyant current interacts with a concave boundary*. Since such curvature would enhance negative shear, the coastal flow may become stagnant, beyond which point anticyclonic eddies would be generated. Numerical calculations using the Lamont Ocean Model (in collaboration with Martin Visbeck) have simulated the above process, and the model results compare favorably with analytical derivations. We are presently examining the T/P data to further evaluate the model.

Generation of intra-thermocline eddies (Fig. 3d): It is hypothesized that *subduction of low-vorticity winter mixed-layer water may cause the generation of ITE*. The cross-frontal circulation associated with the horizontal density gradient causes the mixed layer water - on the poleward side of the front - to

sink along the thermocline. As the mixed layer is thicker in winter and hence of lower potential vorticity, the vertical contraction during subduction would induce ITE of anti-cyclonic vorticity. Moreover, ITE would reach a size when detrainment from the domed upper surface balances the subduction rate. Since such detrainment would modify SST, it could explain the quasi-stationary meandering pattern observed in the polar front. Because of robustness of the proposed mechanism, ITE should be rather widespread and present near other frontal zones.

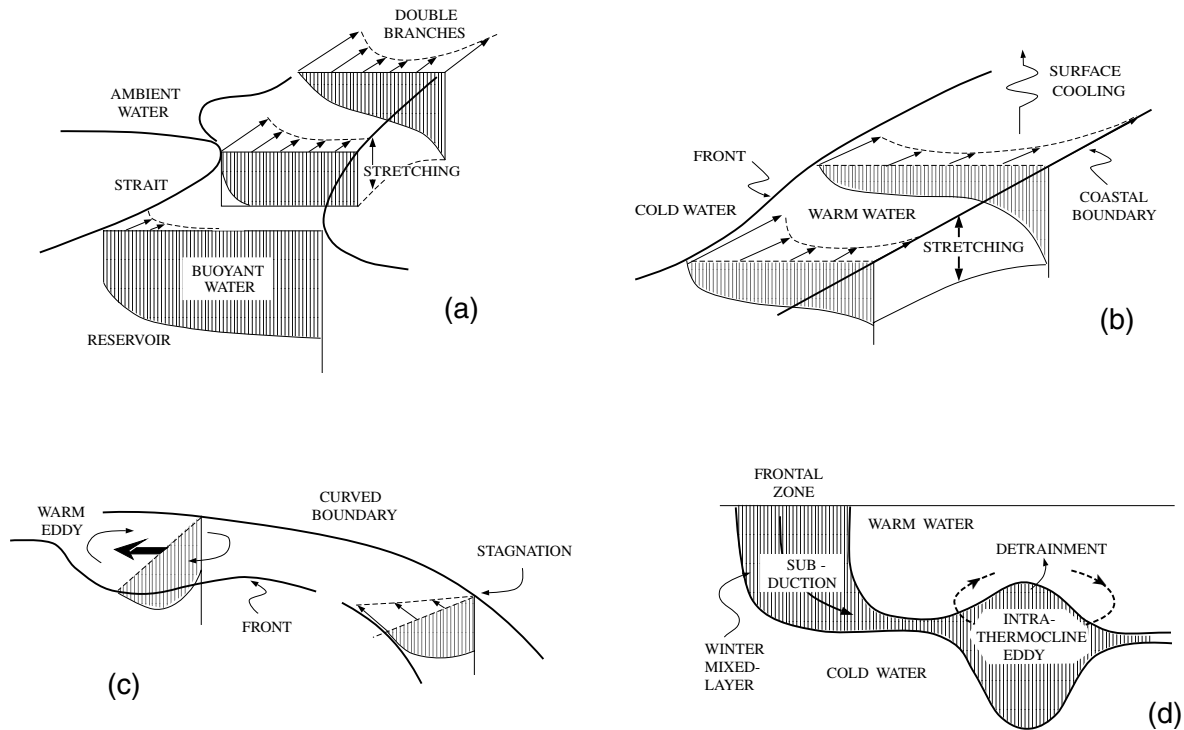


Fig. 3: Schematics of the basic physics contained in the analytical models: a) Branching of the Tsushima Current; b) Cooling of the Tsushima Current; c) Generation of Tsushima warm eddies; d) Generation of intra-thermocline eddies.

TRANSITIONS

The Tsushima Current research will be linked to the rest of the JES program results. The annual JES workshops (see: http://sam.ucsd.edu/onr_jes) provide opportunity to develop such transitions.

RELATED PROJECTS

none

PUBLICATIONS

Ou, H-W. 2000. A model of a buoyant through-flow with application to branching of the Tsushima Current. In press, *J. Phys. Oceanogr.*